(TRB 05-1605)
ESTIMATING CAPACITY FOR UNINTERRUPTED MOTORCYCLE PATH IN MALAYSIA

Hussain H.[1], Radin Umar R.S.[2], Ahmad Farhan M.S.[3], Dadang M.M.[4]

Revised and Submitted on: 15 November 2004
Main content (3,767 words) + Abstract (272 words) + 8 Figures (2,000 words) = 6,039 words

AUTHOR'S INFORMATION:

Hussain Hamid (KEY AUTHOR)
Lecturer
Department of Civil Engineering
Faculty of Engineering, Universiti Putra Malaysia
43400 Serdang, Selangor
MALAYSIA
Fax : 603-86567129
Email-1: hushamid@eng.upm.edu.my
Email-2: hussainhamid@hotmail.com

Ir. Dr. Radin Umar Radin Sohadi
Professor
Road Safety Research Center
Faculty of Engineering, Universiti Putra Malaysia
43400 Serdang, Selangor
MALAYSIA
Fax : 603-86567099
Email : radinumx@eng.upm.edu.my

Dr. Ahmad Farhan Mohd. Sadullah
Associate Professor
School of Civil Engineering, Universiti Sains Malaysia
14300 Nibong Tebal
Seberang Perai Selatan
Pulau Pinang
MALAYSIA
Fax : 604-5941037
Email : cefrhn@eng.usm.my

Dr. Dadang Mohamad Ma'soem
Lecturer
Department of Civil Engineering
Faculty of Engineering, Universiti Putra Malaysia
43400 Serdang, Selangor
MALAYSIA
Fax : 603-86567129
Email : dadang@eng.upm.edu.my

Abstract

In developing countries like ASEAN, the key road accident problems arise from the high proportion of motorcycles in the mixed vehicles population. Considering that motorcyclists formed the major road users, the provision of motorcycle facilities would significantly reduce accident and improve motorcycle safety. But studies on capacity of motorcycle facilities were overlooked. This paper attempts to establish the fundamental motorcycle speed-flow-density relationships along uninterrupted motorcycle path in Malaysia. Initial findings enable the maximum motorcycle flow, critical speed and critical density at capacity conditions to be estimated. It threw light in designing motorcycle path for developing and highly motorcycled countries.

Field and experimented observations of motorcycle flow and speed passing through different path widths were conducted along the present motorcycle path of Federal Highway, Selangor, Malaysia and in Universiti Putra Malaysia campus. Data were collected by means of a digital video camera, laser speed detector, and horizontal distance measurer. From the aggregated data collected, the fundamental diagrams of motorcycle speed-flow-density relationships ranging from the stable flow to unstable conditions were plotted. Linear regression analysis was employed in the model building process.

Results indicated that under the headway concept ($W \leq 1.7$ m), capacity is reached at a maximum motorcycle flow of 3306 mc/hr/lane, corresponding to a critical speed of 13 km/hr and critical density of 235 mc/km/lane. As for the space concept ($W > 1.7$ m), capacity occurs at a maximum motorcycle flow of 2207 mc/hr/m. This corresponds to a critical motorcycle speed of 13 km/hr and critical motorcycle density of 0.166 mc/m^2 (or space of 6.0 m^2/mc). The outcome is an initial effort to fill the missing link in capacity studies among various land transportation facilities.

Keywords: Motorcycle accidents, Motorcycle facilities, Missing link, Fundamental relationships, Capacity.

---

1. INTRODUCTION

Unlike the developed countries, the road safety problems in the developing world, especially ASEAN countries are worsening. Road accident costs incurred about 2% of their gross domestic product (GDP) and, on this basis, the cost to ASEAN countries is estimated at over USD11 billion per year. These recurring economic losses inhibited its economic and social development. One of the major reasons is related to the high proportion of two- and three-wheeled vehicles in its mixed vehicle population (Vietnam [95%], Lao People's Democratic Republic [79%], Cambodia [75%] and Indonesia [73%]). The fact that the present vehicle growth has been in motorcycles exacerbated the already dangerous traffic environment. For instance, the number of motorcycles in Vietnam increased by 29% in 2001, resulting with a 39% increase in road deaths that year (*1*). The Asian Institute of Technology in Bangkok generalized that the high proportion of motorcycles on Thailand's roads is linked to a higher death rate. Of the country's 26 million registered vehicles, 12 million are two-wheelers while there are another 6 million unregistered motorcycles. About 80% of all fatal accidents in Thailand involve motorcycles (*2*). In Malaysia, motorcycles constitute about 55% of all registered vehicles while almost 60% of all road accident fatalities were motorcyclists (*3*).

Motorcycles are popular in many parts of Asia because almost anyone can afford one. The implications from the fact that motorcyclists are the major road users in these countries cannot be ignored; and something must be done to cater for the safety and travel needs of these vulnerable road users. Literature has proved that segregating motorcycles from other traffic by means of motorcycle facilities have reduced the accident exposure and have significantly improved the safety of motorcyclists (*3*, *4*). Based on these advantages, Malaysia is championing the provision of motorcycle facilities to its neighboring countries. As in other land transportation facilities, the understanding of the capacity of a motorcycle facility is essential before a transport engineer could design and construct this facility.

However, available literature on the capacity of transportation facilities commonly emerging from developed countries seems to overlook motorcycle facilities. This is expected as these countries have very low motorcycle population thus not warranting studies on motorcycle facilities. In the United Kingdom, the number of motorcycles, scooters and mopeds make up only 3% of the total registered vehicles in year 2001 (*5*).

This paper attempts to establish the fundamental motorcycle speed-flow-density relationships along an uninterrupted motorcycle path in Malaysia. These initial findings enable the estimation of the maximum motorcycle flow, critical motorcycle speed, critical motorcycle density at capacity conditions, and jam density at breakdown conditions. Apart from indicating the range of values to define the level-of-service criteria, it also gives some guidance to engineers towards designing motorcycle path in developing and highly motorcycled countries. This study was seen as initiative to fill the knowledge gap in capacity studies that existed among the various land transportation facilities, thus contributing new knowledge to the field of transportation engineering.

2. CAPACITY OF VULNERABLE ROAD USERS' FACILITIES

In the search for literature related to the motorcycle facility, the guidelines for the design of a cycle lane (or referred as motorcycle track) that were published by the Public Works Department, Ministry of Works Malaysia (*6*, *7*) seems to be the closest available information. However, most of the elements of design were inclined towards a bicycle track. The design speed was 60 km/hr. It recommended that for motorcycle volume ranging 1000-1500 per hour, the minimum and desired width are 2.0 m and 2.5 m respectively. For motorcycle volumes higher than 2000 per hour, a minimum width of 3.0 m and desired width of 3.5 m should be applied. The source or approach towards obtaining these recommended values were not clarified. There was no mentioned on the capacity or level of service of this facility. In a study related to motorcycle/rider characteristics (*8*), it

was found that small- and medium-sized motorcycles (less than 250 c.c.) represented 99% of all motorcycles in Malaysia. In terms of space requirement, the static handlebar width of a motorcycle/rider unit is 0.8 m. The operating width ranged from 0.9 m to 1.7 m with a mean width of 1.3 m. It was observed that motorcyclists riding manner were influenced by the available width of the motorcycle path. Constrained by the total width of 1.7 m or less, motorcyclists ride in a single file both during low or high flow. Thus, under this condition, the headway (or platoon) concept is applicable, i.e. motorcycle flow is measured in mc/hr/ln. On the other hand, motorcyclists formed into more than two lines either during low or high flow for total widths of more than 1.7 m. As such, the space concept is applied; i.e. motorcycle flow is expressed in mc/hr/m-width.

There were significant numbers of literature related to the bicycle facility as compared to the motorcycle facility. It was stated that bicyclists tend to operate in distinct lanes of varying widths. The capacity of a bicycle facility depends on the number of effective lanes used by bicycles rather than the total width of the bicycle facility or of the individual lanes (*9*). The capacity of one-way and two-way bicycle facilities were reported to range from 1700–2530 bicycles/hr and 500–2000 bicycles/hr respectively (*10*). In one study, the bicycle saturation flow rates were obtained by experimentation for three different bike-lane widths. The capacity of a bicycle facility was cited as 0.22 bicycles per second per foot of bicycle path. This is equivalent to 2,376 bicycles/hour for a 3-ft (0.91-m) bicycle path (*11*). As for exclusive bicycle facilities operating under uninterrupted flow conditions, studies from Europe indicated capacity values of 1,600 bicycles/hr/ln for two-way facilities, and 3,200 bicycles/hr/ln for one-way facilities (*12*).

Compared to the two vulnerable road users, studies on the pedestrian facilities were better researched. The pedestrian capacity terminologies, principles of pedestrian flow, fundamental relationships, capacity and level-of-service of the facility were discussed (*9, 13*). The concept of a pedestrian lane was used to analyze pedestrian flow. But for pedestrian analysis, a space concept was used because studies have shown that pedestrians do not walk in organized lanes. The relationship among speed, density and pedestrian flow is analogous to vehicular traffic streams. Since density values are too small for comparison study, space (the inverse of density) is a more useful expression. In addition, it described the area occupied by one pedestrian. The basic relationship between flow and space recorded by several researchers (*13*) indicated that at flows near capacity, an average space of 0.4 to 0.9 m^2/p is needed for each moving pedestrian. As space is reduced to less than 0.4 m^2/p, the flow rate declines precipitously and all movement effectively stops at the minimum space of 0.2 to 0.3 m^2/p. The relationship of walking speed and available space (*13*) suggested some points of demarcation for developing level-of-service criteria.

Overall, the literature review and frequent observations in the field (Fig. 1) threw light on the suitable methodology approach to develop the fundamental relationships for an uninterrupted segment of a motorcycle path.

3. METHODOLOGY

3.1 Data collections

Key parameters measured at the study sites were motorcycle volumes, individual motorcycle spot speeds, and total paved widths of the motorcycle path. Motorcyclists riding along the paths were captured using a digital video recording camera, and volumes counted in the laboratory from a large screen television. Simultaneously, individual motorcycle spot speeds were measured using a portable laser speed detector. Time of internal clocks for both laser speed detector and digital video recorder were synchronized before conducting the observations. Total width of motorcycle path was measured across the paved section using a horizontal distance measurer. Parameters measured at each study site were reduced into the following format:

(i) Motorcycle time-mean speeds (S_t) at 1-minute interval (measured in kilometers per hour),
(ii) Motorcycle volumes (V_c) at 1-minute interval (counted in number of motorcycles),
(iii) Total widths (W_t) of the motorcycle path (measured in meters).

Time-mean speeds were converted to space-mean speeds according to established traffic flow theories (*14*). Motorcycle volume collected in 1 minute was converted to an equivalent rate of flow in motorcycles per hour. For the space concept, the rate of flow per unit width was obtained by dividing the rate of flow with the total width of the motorcycle path. In addition, to fulfill the requirements of dimensional analysis in the computation, the speed in kilometer per hour was converted into meter per hour.

3.2 Field and experimented study sites

In an attempt to collect data ranging from the stable-flow to unstable-flow conditions, the study was conducted in three stages. In the initial stage, data was collected at three sites of the motorcycle path along the Federal Highway Route 2 (FO2) in the state of Selangor, Malaysia. All sites were level and have straight path at the diverging, merging and basic segments with total widths of 2.4 m, 3.0 m and 3.3 m respectively. However, observations from these three sites only exhibited the initial portion of a stable flow condition even under peak hour conditions and minimum width of 2.4 m. Field observations of motorcycle flow at capacity and near-jam density conditions were not possible unless the widths were made smaller than 2.4 m and coupled with considerably high motorcycle flows.

In the second stage, three experimental studies representing three different widths of less than 2.4 m were conducted in the Universiti Putra Malaysia campus. The experimental studies involved 100 motorcyclists riding along level and straight basic segments that were narrowed down on one side by safety cones. The experimental total widths were 1.5 m, 1.7 m and 1.9 m respectively.

Based on the success of experimental studies in obtaining data covering capacity and near-jam density conditions, similar experimental studies were conducted along the motorcycle path along the FO2 highway. In this third stage, the experimental studies were conducted on the morning peak hour motorcycle traffic riding along the level and straight basic segments of experimental total widths 1.4 m, 1.6 m and 2.0 m respectively.

3.3 Data analysis

A total of 193 data points measured at 1-minute interval were aggregated from the study sites. It covered a range of total widths from 1.4 m to 3.3 m. Adopting an earlier findings (*8*), the headway concept covered data points belonging to total widths of 1.7 m or less. For the purpose of comparison, the space concept encompassed all data points. Scatter plot diagrams were obtained for three relationships; i.e. Flow (v)-Speed (S), Flow (v)-Density (D), and Speed (S)-Density (D).

The initial calibrations focused on the S-D relationships because S-D curves are monotonically decreasing and involve simpler mathematical forms than the other two curves. In addition, S-D curves represent the most basic interaction of drivers/riders and vehicles on the road. Drivers/riders adjust their speed according to the perceived proximity of other vehicles (density). Flow does not influence behavior, but is a product of speed and density. Since v = S x D, the calibration of S-D relationship leads to the derivation of the other two relationships. Various forms have been postulated for the shape of the S-D relationship (*15*). The shapes ranged from linear interpretations, discontinuities, logarithmic and exponential descriptions.

The model-building process for the S-D relationship incorporated scientific knowledge of Greenberg's logarithmic model in the model selection (*16*). Linear regression analysis at 95% confidence interval was employed for the model fitting and model validation process by using the Statistical Package for Social Sciences software (SPSS). The three underlying assumptions were that random errors are independent from one another (Durbin-Watson, d_u), have constant variance (Scatter diagram), and are distributed normally (P-P plot).

4. RESULTS

4.1 Headway concept (Total lane width ≤ 1.7 m)

From the linear regression analysis, motorcycle speed (*S*) versus motorcycle density (*D*) relationship may be described in a linear form as:

$$S = 84 - 13\ln(D) \quad \text{Eq. (1)}$$

Based on Greenberg's logarithmic model which may be expressed in linear form as:

$$S = S_c \ln(D_j) - S_c \ln(D) \quad \text{Eq. (2)}$$

the following results were obtained:

Jam motorcycle density, D_j	=	640 mc/km/ln
Critical motorcycle speed, S_c	=	13 km/hr
Critical motorcycle density, D_c	=	235 mc/km/ln
Maximum motorcycle flow, F_{max}	=	3060 mc/hr/ln

Hence, the fundamental motorcycle speed-flow-density relationships may be expressed as follows:

4.1.1 Motorcycle speed versus motorcycle density (Fig. 2)

$$S = 13\ln(640/D) \quad \text{Eq. (3)}$$

4.1.2 Motorcycle flow versus motorcycle density (Fig. 3)

$$F = 13\,D\ln(640/D) \quad \text{Eq. (4)}$$

4.1.3 Motorcycle speed versus motorcycle flow (Fig. 4)

$$F = 640\,S\,e^{(-S/13)} \quad \text{Eq. (5)}$$

(Note: $D \geq 11$ mc/km/ln)

4.2 Space concept (Total lane width > 1.7 m)

Similarly, the linear regression analysis of motorcycle speed (*S*) versus motorcycle density (*D*) relationship may be described in the following linear form:

$$S = -10759 - 13330 \ln(D) \quad \text{Eq. (6)}$$

Based on Greenberg's model, the following results were computed:

Jam motorcycle density, D_j	=	0.45 mc/m^2 (or Space, $M_j = 1/D_j$ = 2.2 m^2/mc)
Critical motorcycle speed, S_c	=	13330 m/hr (13 km/hr)
Critical motorcycle density, D_c	=	0.166 mc/m^2 (or Space, $M_c = 1/D_c$ = 6.0 m^2/mc)
Maximum motorcycle flow, F_{max}	=	2207 mc/hr/m

The fundamental motorcycle speed-flow-density relationships is described as follows:

4.2.1 Motorcycle speed versus motorcycle density (Fig. 5)

$$S = 13330 \ln(0.45/D) \quad \text{Eq. (7)}$$

4.2.2 Motorcycle flow versus motorcycle density (Fig. 6)

$$F = 13330D \ln(0.45/D) \quad \text{Eq. (8)}$$

4.2.3 Motorcycle speed versus motorcycle flow (Fig. 7)

$$F = 0.45\, Se^{(-S/13330)} \quad \text{Eq. (9)}$$

(Note: $D \geq 0.003$ mc/m^2)

4.3 Capacity values for various motorcycle lane widths

Based on the capacity values for both headway and space concept, the estimated maximum motorcycle flow for a range of motorcycle lane widths were computed and summarized in the form of a chart.

Fig. 8

5. DISCUSSION AND CONCLUSIONS

Overall, this study found that the motorcycle speed-flow-density relationships for both the headway concept ($W \leq 1.7$ m, motorcycle flow expressed in mc/hr/ln) and space concept ($W > 1.7$ m, motorcycle flow expressed in mc/hr/m) are analogous to vehicular traffic streams. Similar to the vehicular traffic streams, the relationship between motorcycle speed and motorcycle density (Fig. 2 and Fig. 5) indicated that as motorcycle density increases, motorcycle speed decreases. This trend continues until a jam density condition is reached where density becomes so high that all motorcycles

practically come to a stop. In the headway concept, a jam density condition of 640 mc/km/ln was observed, while the space concept resulted with a jam density at 0.45 mc/m^2 (or space of 2.2 m^2/mc).

The logarithmic description of motorcycle speed-density adopted from Greenberg's hypothesis (*16*) took into account the flaw of this model when motorcycle density values approaches zero. Thus, an observed maximum free-flow speed of 53 km/hr corresponding to motorcycle density of 11 mc/km/ln was superimposed for the headway concept model (Fig. 2). Similarly, an observed maximum free-flow speed of 67 km/hr relating to motorcycle density of 0.003 mc/m^2 (or space of 333 m^2/mc) was superimposed for the space concept model (Fig. 5).

In the motorcycle flow-density relationships, both Fig. 3 and Fig. 6 showed that motorcycle flow is zero when motorcycle density is zero. This happens when there are no motorcycles on the motorcycle lane. As motorcycle density increases from zero, motorcycle flow dramatically increases with small increments in density until it reaches a point of maximum flow (capacity) that corresponds to a critical motorcycle density. After this point of capacity, motorcycle flow starts to gradually decrease with further increase in motorcycle density within an unstable flow region. Motorcycle flow becomes zero when jam density or breakdown condition is reached. Fig. 3 for the headway concept ($W \leq 1.7$ m) indicated that capacity is reached at a critical motorcycle density of 235 mc/km/lane corresponding to a maximum motorcycle flow of 3060 mc/hr/ln. Meanwhile Fig. 6 representing the space concept ($W > 1.7$ m) indicated that a critical motorcycle density of 0.166 mc/m^2 (or space of 6.0 m^2/mc), capacity is reached at a corresponding maximum motorcycle flow of 2207 mc/hr/m.

The motorcycle speed-flow relationships (Fig. 4 and Fig. 7) exhibited that after the free-flow speed region, motorcycle speed tend to drop quite drastically with a slight increase in motorcycle flow. This trend in speed reduction continues until flow reaches a maximum value. After this critical motorcycle speed, an unstable flow region happens where motorcycle speed continues to drop but less dramatically with respect to the drop in motorcycle flow. Motorcycle critical speed for headway concept (Fig. 4) and space concept (Fig. 7) was found to be 13 km/hr and 13330 m/hr (13 km/hr) respectively.

The values of the maximum motorcycle flow for headway concept (3060 mc/hr/ln) and space concept (2207 mc/hr/m) obtained from this study threw light on the capacity at level-of-service (LOS) E for an uninterrupted motorcycle path at different lane widths. Fig. 8 showed that capacity at LOS E is maintained at 3060 mc/hr throughout the range of motorcycle lane widths from 1.4 m to 1.7 m. This is so because motorcyclists could only ride in a single file since there is not enough space for overtaking. If space concept were to be applied for this particular condition, a higher capacity value would be incorrectly used. For instance, a 1.7 m wide motorcycle lane would result with a capacity value of 3752 mc/hr at LOS E resulting with the motorcycle lane to be under-designed. Similarly, if a headway concept were employed on a 2.5 m wide motorcycle lane, the capacity value of 3060 mc/hr instead of 5518 mc/hr would result with the motorcycle lane to be over-designed.

It is interesting to note that an "ideal lane width" may be determined from Fig. 8. Knowing that capacity for the headway concept is 3060 mc/hr throughout the lane widths from 1.4 m to 1.7 m, doubling the value of capacity would correspond to twice the "ideal lane width." Therefore, if a horizontal line at a value of 6120 mc/hr is drawn in parallel to the motorcycle lane width axis, the point of interception with the line graph of the space concept could be easily read-off the chart to represent twice the "ideal lane width"; i.e. 2.8 m. Hence, an "ideal lane" may be computed as half of 2.8 m, which is 1.4 m wide. Based on this value, the headway concept is expected throughout the lane widths from 2.8 m to 3.1 m. While above 3.1 m, the space concept is anticipated. It is worth noting that the chart in Fig. 8 is limited to a motorcycle lane of up to 3.5 m wide. This is to reasonably comply with the standard lane width of a highway that ranged between 3.0 m and 3.5 m.

These findings may also be useful as a basis in considering wide curb motorcycle lane along arterial roads. However, it is advisable that the lane width be kept below 3.0 m for wide curb motorcycle lane. This is to prevent errant automobile drivers to utilize the wide curb motorcycle lane as an illegal overtaking lane. Apart from that, other anticipated problems such as junction treatments,

effects of wind blast from heavy vehicles, location of bus-stops, and other safety, comfort and convenience factors must be taken into account.

Finally, even though the fundamental motorcycle speed-flow-density relationships, critical density, critical speed, capacity at LOS E and jam density were established in this study, further studies is still needed to define the LOS criteria for an uninterrupted motorcycle path. It is thought that density would be the most appropriate measure since it best describes the proximity to other motorcycles, which varies with motorcycle flow throughout the full range of flow. Apart from the critical motorcycle density that objectively defined the capacity LOS E, the motorcycle density thresholds for LOS A through D need to be subjectively defined. The knowledge of LOS criteria for various motorcycle lane widths would be useful for traffic engineers to design a motorcycle path according to the available lane widths, desired design LOS and design life. In conclusion, the findings from this study are seen as an initial effort to bridge the missing link in capacity studies that existed among various land transportation facilities. Thus, contributing new knowledge to the field of transportation engineering.

ACKNOWLEDGEMENTS

Data, grants and support for field data collections were provided by the National Science Council IRPA Malaysia, Public Works Department, Ministry of Works Malaysia and Roadcare (Malaysia) Sdn. Bhd.

REFERENCES

1. Melhuish C. M., *Report on Technical Assistance for Road Safety in the Association of Southeast Asian Nations*, Regional and Sustainable Development Department, Asian Development Bank, December 2002, pp. 3-4. (2002)

2. *Mean Streets*, TIME Asia Magazine Issue, August 9, 2004

3. Radin Umar R.S., Murray G. Mackay, Brian L. Hills, Multivariate Analysis of Motorcycle Accidents and the Effects of Exclusive Motorcycle Lane in Malaysia, *Journal of Crash & Injury Control* Vol. 1 No. 1, USA, 1998

4. Radin Umar R.S., Murray G. Mackay, Brian L. Hills, Preliminary Analysis of Exclusive Motorcycle Lane Along the Federal Highway F02, Shah Alam, Malaysia, *Journal of IATSS Research* Vol. 19 No. 2, 1995

5. *Transport Statistics Great Britain 2002*, Department for Transport, United Kingdom, 2002.

6. Arahan Teknik Jalan, 8/86, *A Guide on Geometric Design of Roads*, Public Works Department, Ministry of Works Malaysia, Kuala Lumpur, 1986, pp. 92-98.

7. Arahan Teknik (Jalan), 10/86, *A Guide to the Design of Cycle Track*, Public Works Department, Ministry of Works Malaysia, Kuala Lumpur, 1986.

8. Hussain H., Radin Umar R.S., Ahmad Farhan M.S., Dadang M. M., *Key components of motorcycle-traffic system: A study along the motorcycle path in Malaysia*, 2004 (unpublished)

9. *Highway Capacity Manual, 4th edition*, Transportation Research Board, National Research Council, Washington, DC, 2000

10. *Highway Capacity Manual, 2nd edition*, Transportation Research Board, National Research Council, Washington, DC, 1985

11. Federal Highway Administration (FHWA), *Safety and Locational Criteria for Bicycle Facilities, Users Manual, Vol. 2*, U.S. Department of Transportation, Washington, D.C. 1976

12. Botma, H., Method to Determine Levels of Service for Bicycle Paths and Pedestrian-Bicycle Paths, *TRR 1502*, *Transportation Research Board*, National Research Council, Washington, D.C., 1995, pp. 38-44.

13. Pushkarev, B., and J. Zupan, *Urban Space for Pedestrians*, The MIT Press, Cambridge, Mass., USA, 1975.

14. Wardrop J.G., *Some Theoretical Aspects of Road Traffic Research*, Proceedings of the Institution of Civil Engineers, Road Paper No.2 (Part 1), London, 1952, pp. 326-331

15. Gerlough, D., and Huber, M., *Traffic Flow Theory: A Monograph, Special Report* 165, Transportation Research Board, National Research Council, Washington, DC, 1975.

16. Greenberg, H., "An Analysis of Traffic Flows," *Operations Research*, Vol. 7, ORSA, Washington, DC, 1959.

LIST OF FIGURES

FIGURE 1 Motorcyclists riding manner along a motorcycle path in Malaysia (W_t = 3.0 m)

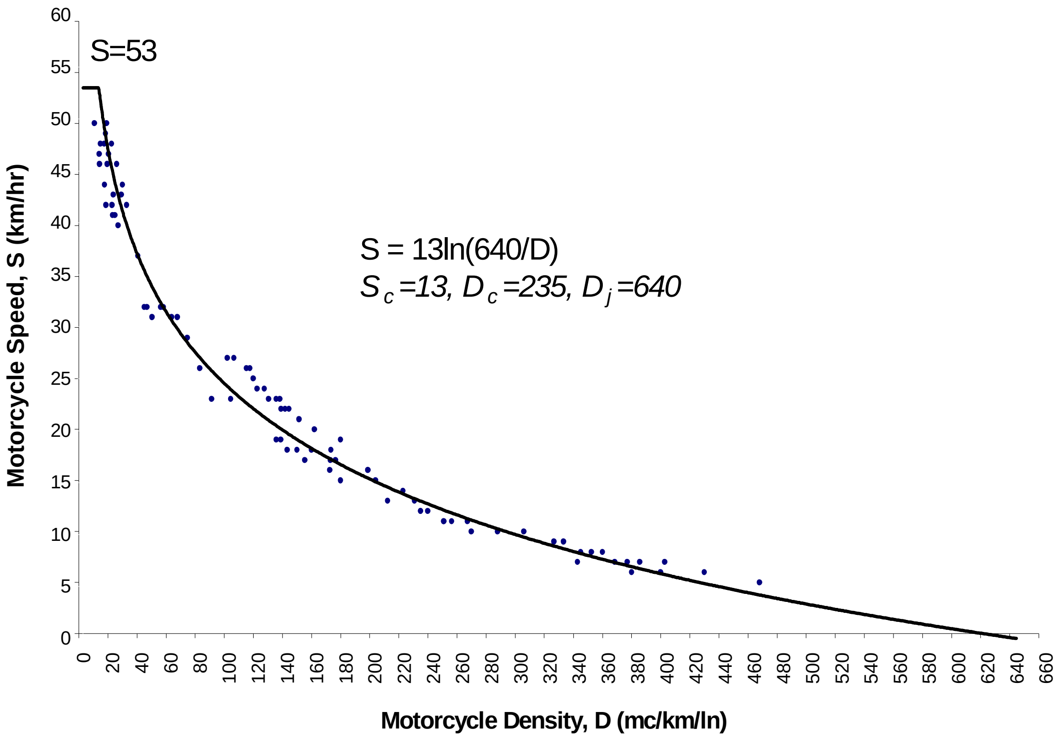

FIGURE 2 Relationship between motorcycle speed and density (Headway concept) (R^2=0.98, N=90, p<0.05, d_u=1.70)

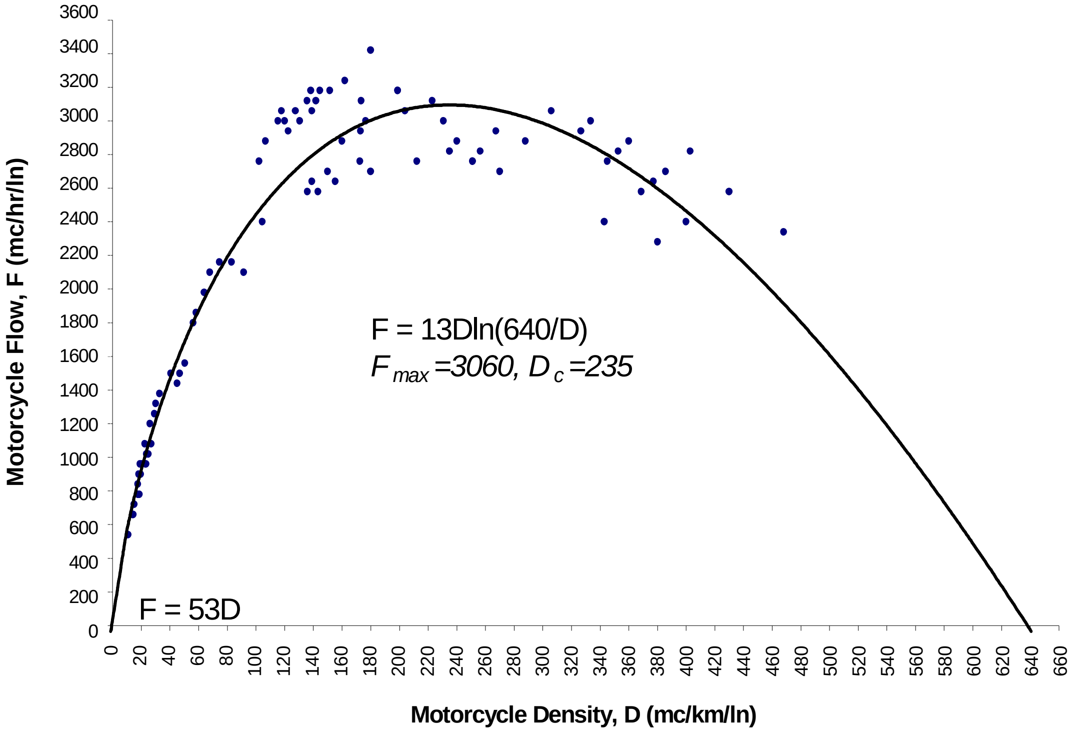

FIGURE 3 Relationship between motorcycle flow and motorcycle density (Headway concept)

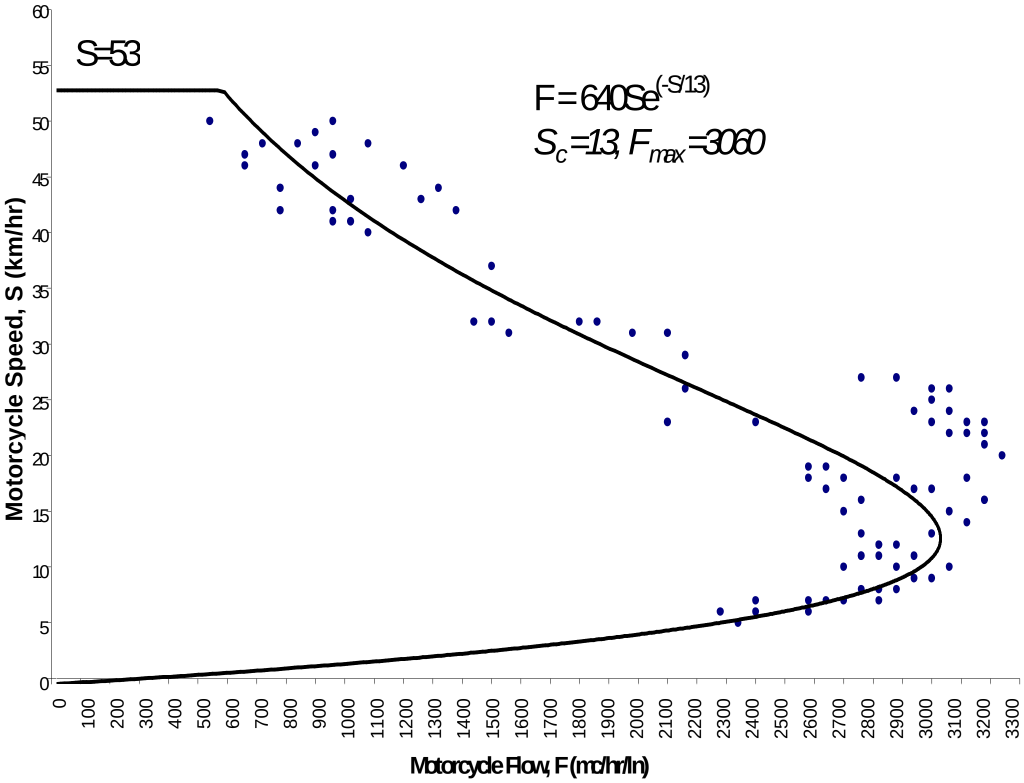

FIGURE 4 Relationship between motorcycle speed and flow (Headway concept)

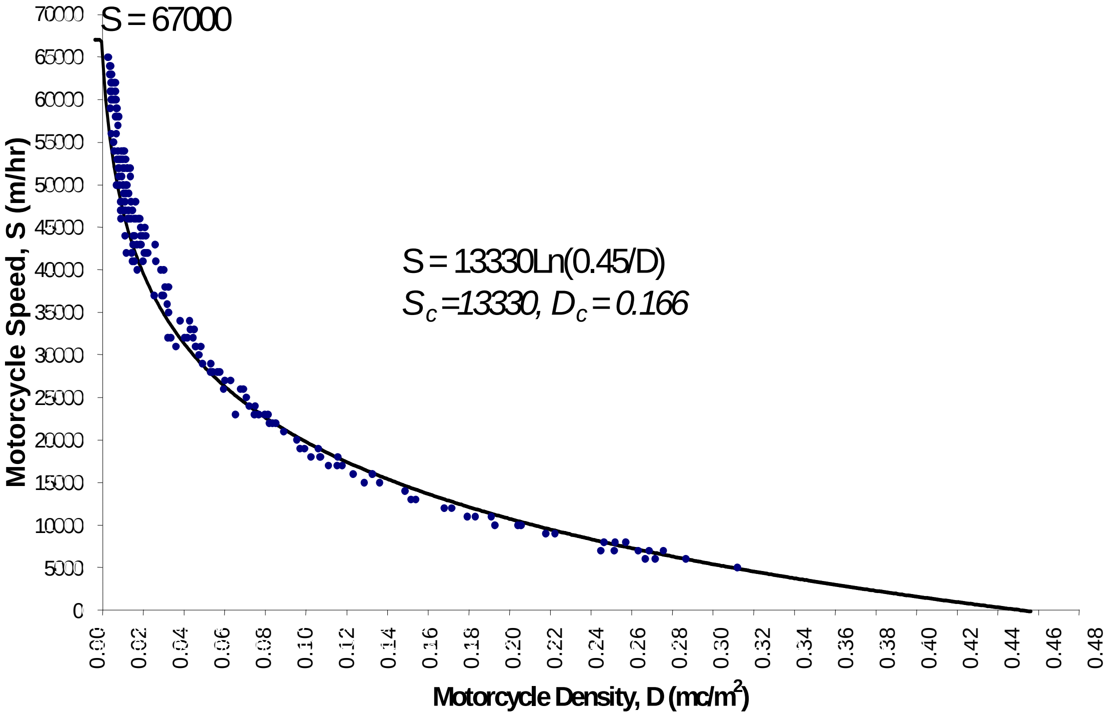

FIGURE 5 Relationship between motorcycle speed and density (Space concept) (R^2=0.98, N=193, $p<0.05$, d_u=1.91)

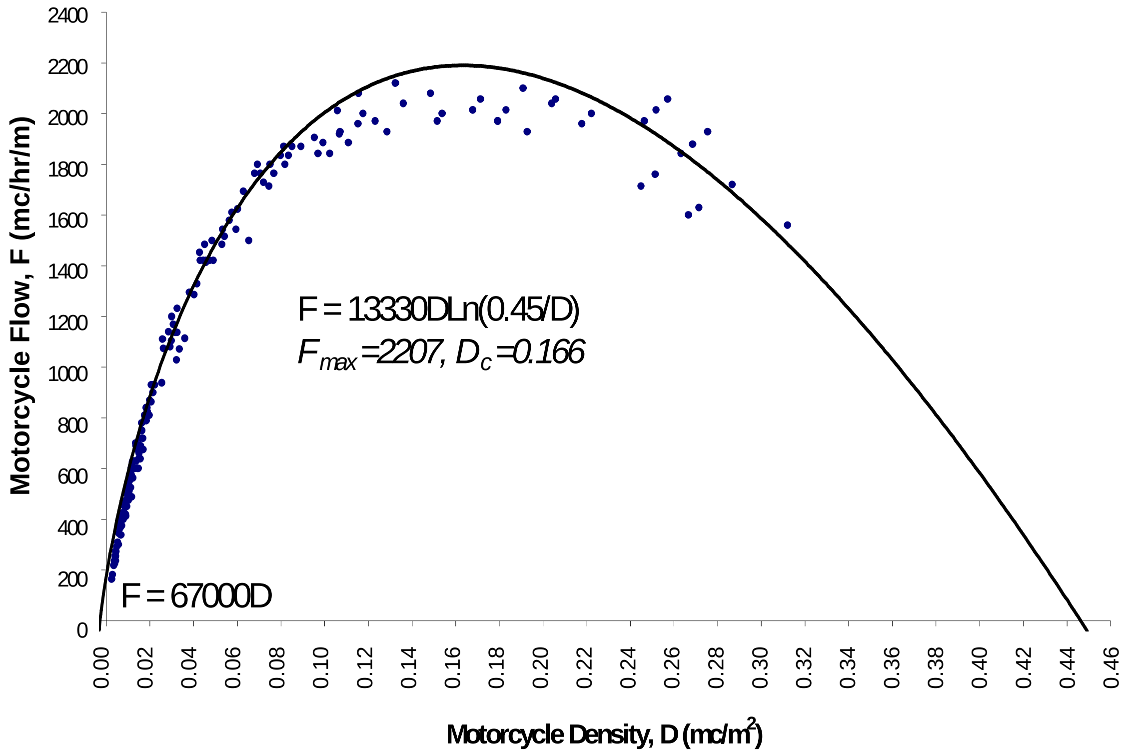

FIGURE 6 Relationship between motorcycle flow and motorcycle density (Space concept)

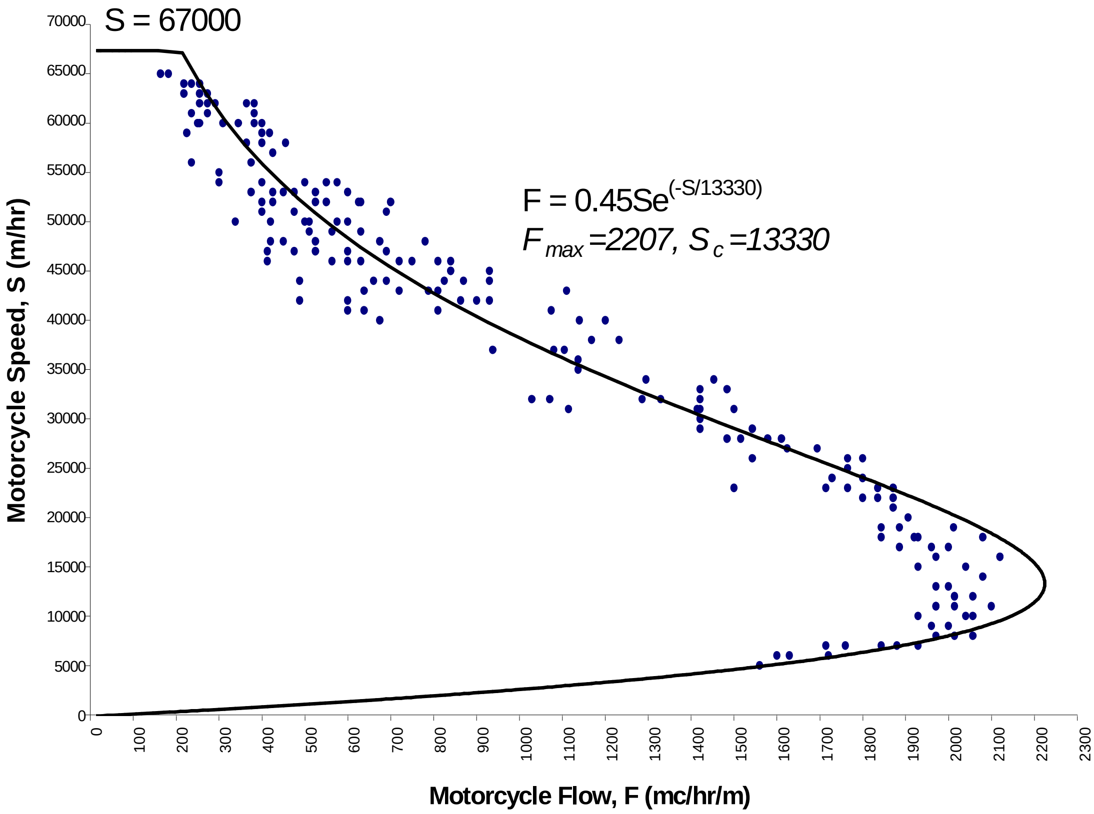

FIGURE 7 Relationship between motorcycle speed and flow (Space concept)

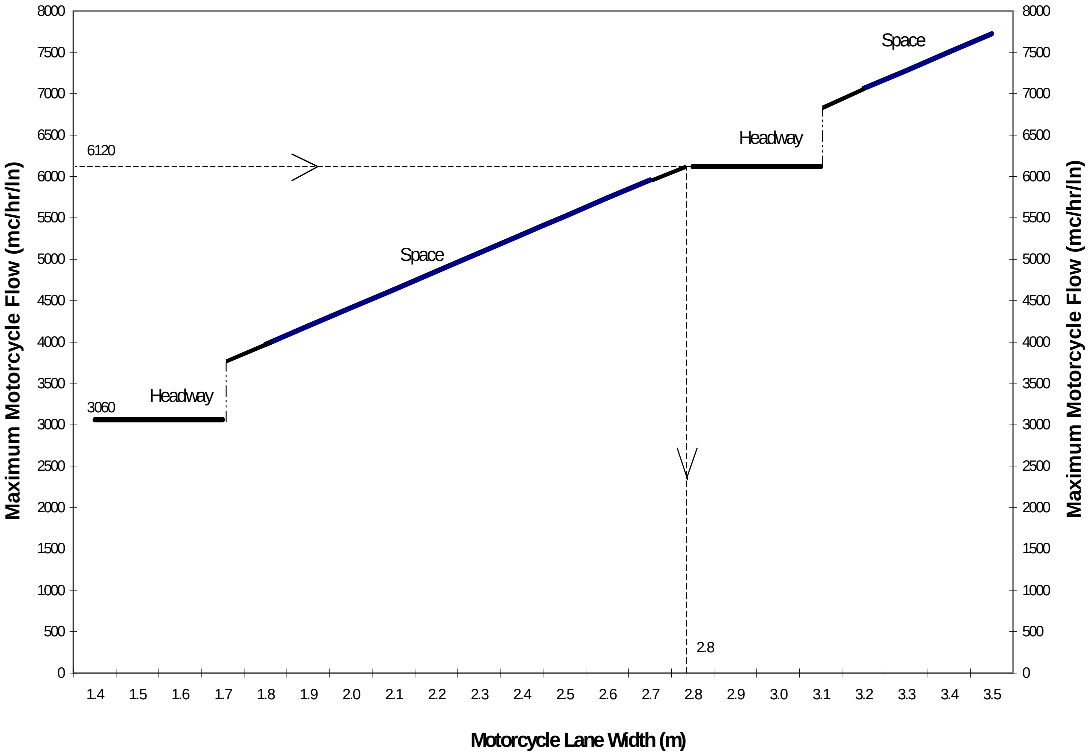

FIGURE 8 Maximum motorcycle flows for various motorcycle lane width